

Emerging Technologies for Controlling Marine Engine Emissions

Presented to:

*Conference on
Marine Vessels & Air Quality*

By

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Introduction

- ◆ SwRI
- ◆ Emerging technologies
 - Near term
 - » Electronic engine management
 - » Fuel composition
 - » Exhaust aftertreatment
 - » EGR
 - Long term
 - » Water-fuel emulsion
 - » Alternative fuels
 - » HCCI
- ◆ Closing thoughts



Southwest Research Institute

Located in San Antonio, Texas



Founded 1947

~2,700 employees, 170 buildings on 1,200 acres

1.7 million sq ft of office & lab space (185,000 m²)

FY 1999 revenue over \$308 million



Southwest Research Institute

- ◆ Best described by what SwRI is **not**:

- Not a Government lab
- Not associated with any University or Industry
- Not publicly held

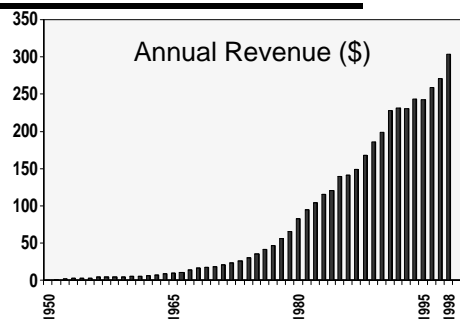
- ◆ SwRI is not-for-profit

- ◆ Focused contract R&D

- ◆ Unique patent policy

- 37 Patents in 1998

- ◆ 50 / 50 mix (commercial / government)



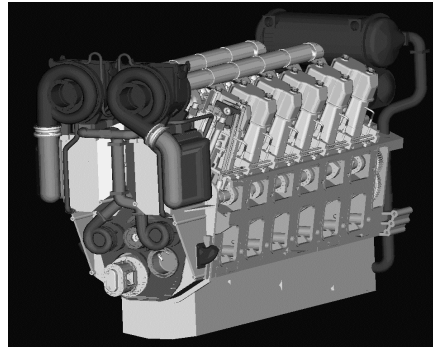
- ◆ SwRI is divided into 11 technical divisions



Division 03

Department of Engine Research

- ◆ Engine Testing
 - Emissions
 - Performance
 - Fuel economy
- ◆ Engine Development
 - Alternative fuels
 - Performance
- ◆ Engine Design
 - Design
 - » Component & clean sheet
 - Analysis



- ◆ Strong focus on quality
 - ISO-9001 certified
 - Ford Q1 status



Near Term Solutions

- ◆ Electronic engine management
 - Injection equipment
- ◆ Diesel & heavy fuels
- ◆ Exhaust aftertreatment
- ◆ Exhaust Gas Recirculation (EGR)



Near Term Solution

Electronic Management

◆ Injection Equipment

- Electronic controlled jerk pumps (EFI)
- Electronic controlled unit injectors (EUI)
- Common rail (CR)

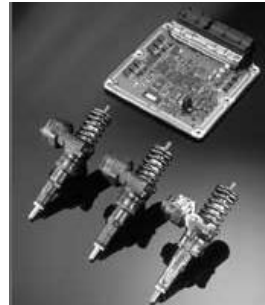
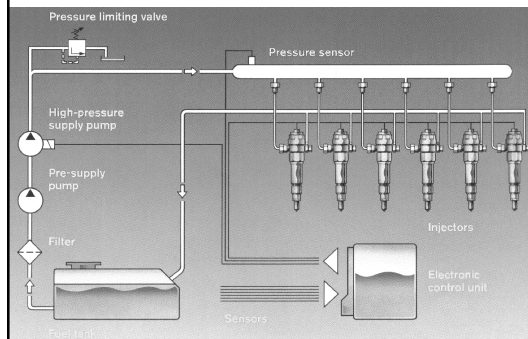


Photo from www.Boschusa.com

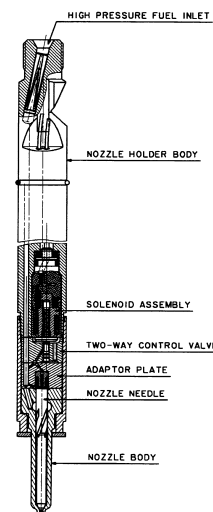


Near Term Solution

Electronic Management (cont'd)

◆ Injection Equipment (cont'd)

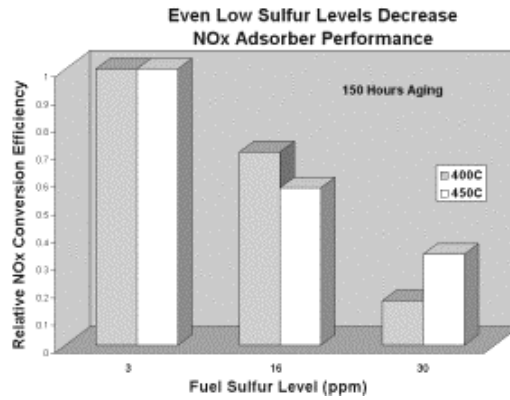
- Injection rate shaping for
 - » Improved performance
 - » Improved fuel economy
 - » Emissions reduction
 - » Improved catalyst operation
- Pilot Injection
- Post Injection
- Common rail provides full authority injection timing & duration (not cam limited)



Near Term Solution

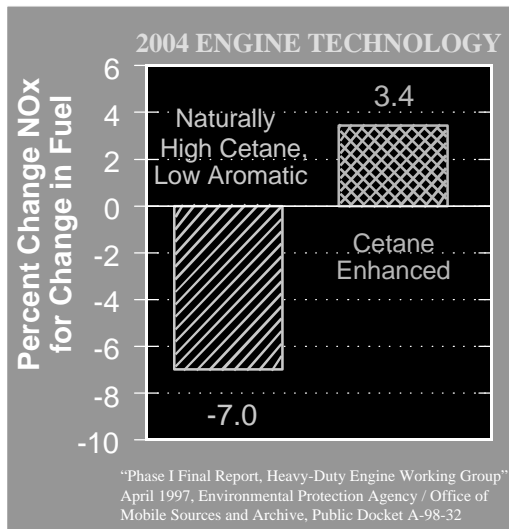
Diesel and Heavy Fuels

- ◆ Low sulfur fuels
 - PM reduction
 - SO₂ reduction
 - Near 0% sulfur required for NO_x catalyst
- ◆ High cetane fuels
- ◆ Fischer-Tropsch fuel
 - Produced from NG
 - High cetane
 - Very low sulfur



Near Term Solution

Diesel and Heavy Fuels (cont'd)



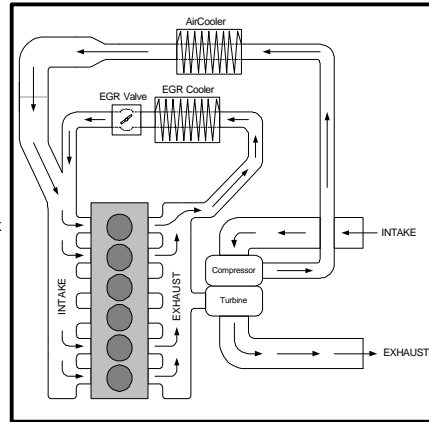
- ◆ Some cetane enhancing additives can increase NO_x emissions



Near Term Solution

EGR

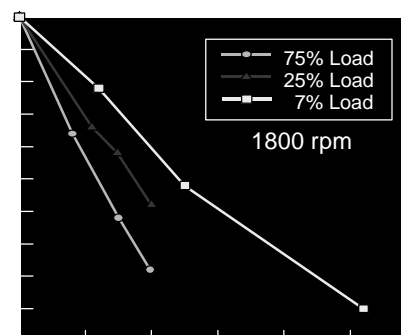
- ◆ Used in
 - Automotive applications
 - On-highway diesel engines
- ◆ Reduces NO_x emissions in diesel engines
 - Cool EGR desired for max. NO_x reduction
 - Additional cooling required
 - Additional plumbing and heat exchangers



Near Term Solution

EGR (cont'd)

- ◆ Can have adverse effect on PM emissions
 - Oil contamination with soot
 - Wear issues
 - Deposits



Near Term Solution

Exhaust Aftertreatment

- ◆ PM Traps
- ◆ Oxidation Cat
- ◆ SCR

Technology	PM Reduction	NOx Reduction	HC Reduction	CO Reduction
Diesel particulate filter	>90%	n.a.	>90%	>90%
Diesel oxidation catalyst	>30%	n.a.	>90%	>90%
Selective catalytic reduction	>30%	>90%	>70%	>50%

- ◆ Watch for:
 - Lean NO_x catalyst
 - Lean NO_x trap
 - Non-thermal plasma reactor



Long Term Solutions

- ◆ Water-fuel emulsion
- ◆ Electronic Valve Actuation (EVA)
- ◆ Alternative fuels
 - Lean burn
 - Stoic combustion
- ◆ Synthesis Gas
- ◆ Homogeneous Charge Compression Ignition (HCCI)



Long Term Solutions

Water Fuel Emulsion

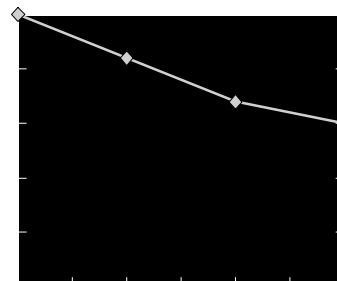
- ◆ Water-fuel emulsion can reduce
 - NO_x emissions
 - PM emissions
- ◆ Increase fuel economy
- ➔ ***All of these benefits can be accomplished simultaneously - If done right!***
- ◆ The water
 - Reduces soot formation (PM emissions)
 - Cools the combustion flame (NO_x formation)
 - Phase change & chemistry = improved efficiency



Long Term Solutions

Water Fuel Emulsion (cont'd)

- ◆ Injector design modifications often required
- ◆ For steady state operation
 - Homogeneous mixture of fuel & H₂O
 - Surfactant to keep the water in suspension
- ◆ For transient operation
 - Cycle-by-cycle (or real time) control of water injection for best results
- ◆ Water supply required (filtered and deionized)



6 Liter engine, 2000 rev/min, 80% Load



Long Term Solutions

Electronic Valve Actuation

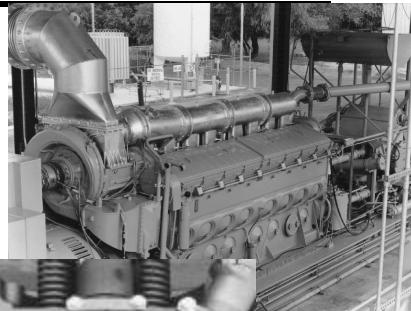
- ◆ Electronic Valve Actuation
 - Can be used for Miller Cycle
 - » Minimize emissions
 - » Maximum performance
 - Variable CR
 - » Better cold starting
 - » Reduced white smoke
 - Use with aftertreatment control exhaust temperature
 - ◆ Catalyst light off
 - ◆ Control catalyst regeneration
 - » Exhaust gas preparation
 - ◆ Catalyst efficiency



Long Term Solutions

Alternative Fuels

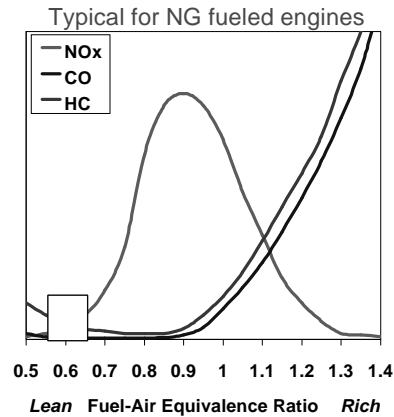
- ◆ Fuels of key interest
 - Natural Gas (NG)
 - Propane
 - Hydrogen
- ◆ NG (as CNG or LNG) most practical and cost effective
- ◆ Some work already done on large engines used in LNG transports



Long Term Solutions

Lean Burn Engines

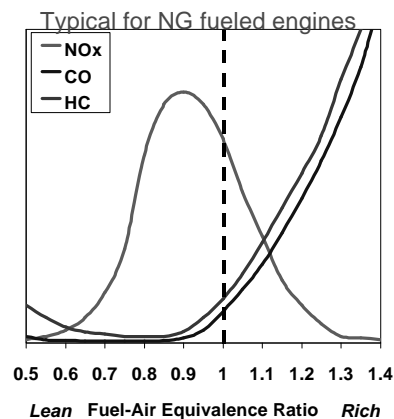
- ◆ Heavy use in stationary & HD on-highway engines
- ◆ Lean Burn = low emissions & good fuel economy
- ◆ Can be used on any of the Alt fuels listed
- ◆ Note box on graph
 - Low NO_x
 - Low CO
 - Low HC



Long Term Solutions

Stoic Fueled Engines

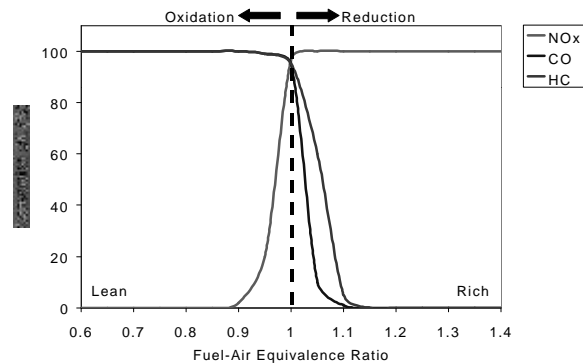
- ◆ Chemically correct A/F ratio
- ◆ Works with NG & LPG fuels
- ◆ Not feasible for hydrogen
- ◆ Fuel economy less than lean burn
- ◆ High combustion and exhaust temperatures
- ◆ Allows use of three way catalyst
 - Very low emissions
- ◆ Exhaust Gas Recirculation (EGR) used for dilution



Long Term Solutions

Stoic Fueled Engines (cont'd)

Catalyst Conversion Efficiency



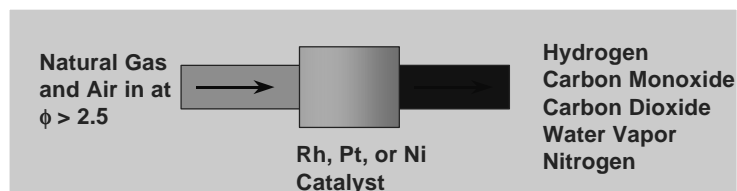
- ◆ Accurate control of A/F ratio required to maintain catalyst efficiency



Long Term Solutions

Synthesis Gas

- ◆ Also known as "Syngas"
- ◆ Hydrogen source for combustion enhancement
- ◆ H₂ produced by rich combustion of natural gas and air over catalyst (low soot)



Long Term Solutions

Synthesis Gas (cont'd)

Advantages of synthesis gas when used with:

Lean Burn Engine

- H_2 can extend lean limit
 - Much cheaper than SCR on lean-burn

Stoichiometric Engine

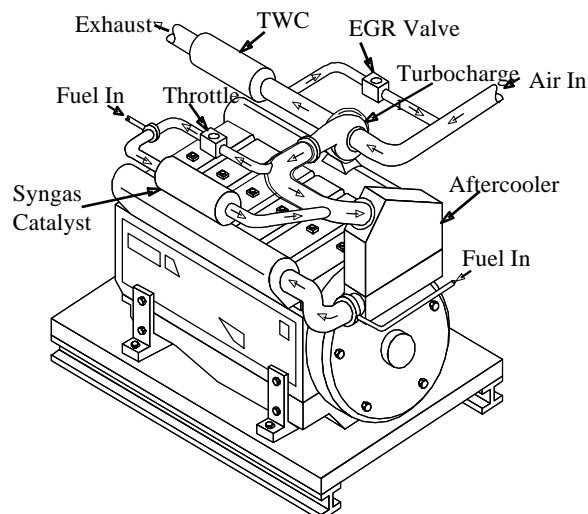
- H_2 extends EGR tolerance
 - EGR tolerance increased by up to 44%
 - High EGR dilution rates provide:
 - » Reduced exhaust temp to lean-burn levels
 - » Increased power density
 - » Reduced engine-out NO_x by 77%
 - Use TWC to reach $NO_x < 15$ ppm



Long Term Solutions

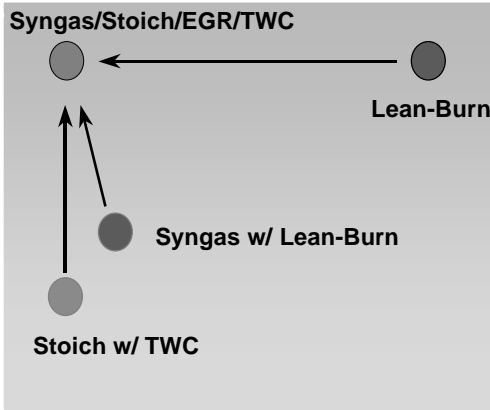
Synthesis Gas (cont'd)

◆ Syngas for Stoic Engine w/EGR



Long Term Solutions

Synthesis Gas (cont'd)



Long Term Solutions

HCCI

- ◆ What is HCCI?
 - Homogeneous mixture of fuel (or fuels) & air
 - Compression ignition



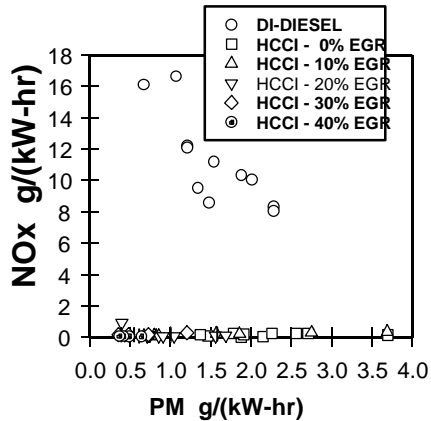
- ◆ Spontaneous reaction throughout cylinder
- ◆ Low temperature reaction creates low NO_x



Long Term Solutions

HCCI (cont'd)

- ◆ Used to produce ultra low NO_x emissions
 - 95% reduction from diesel levels
- ◆ High efficiency
 - Near diesel levels while producing low emissions
- ◆ Issues
 - Control start of combustion
 - » Has been demonstrated by using 2 fuels
 - Full load
 - » Laboratory engine at 35% of peak torque



Closing Thoughts

- ◆ Keep informed!
 - Conferences
 - » Upcoming example
 - ◆ ASME, ICE Division
 - 2001 Spring Technical Conference (April 29 – May 2, 2001)
 - Host - **U.S. Navy Surface Warfare Center, Philadelphia, PA**
 - Web sights
 - » www.asme.org/divisions/ice
 - » www.sae.org
 - » www.MECA.org
 - » www.SwRI.org
 - Publications
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